CEEPA Discussion Paper Series
ISBN 0-9584508-1-1
Discussion Paper ISBN 0-9584508-2-X March 2002

NATURAL RESOURCE ACCOUNTING AND SOUTH AFRICAN FISHERIES:
A BIO-ECONOMIC ASSESSMENT OF THE WEST COAST DEEP-SEA HAKE FISHERY WITH REFERENCE TO THE OPTIMAL UTILISATION AND MANAGEMENT OF THE RESOURCE

Trevor Hutton
Fisheries Centre, University of British Columbia, Vancouver, Canada
and
U.R. Sumaila
Chr. Michelsen Institute, Fantoft, Bergen, Norway

CEEPA
The Centre for Environmental Economics and Policy in Africa

University of Pretoria

This study was carried under a research grant from The Resource Accounting Network for Eastern and Southern Africa (RANESA). RANESA is a non-profit network that aims to support capacity building and awareness in environmental economics and policy in Africa through research, training, networking and public education and awareness activities. The network is funded by the Swedish International Development Agency (SIDA) and coordinated jointly by CEEPA at the University of Pretoria and the Beijer International Institute of Ecological Economics in Stockholm. For more information about RANESA visit the network's website at: www.ceepa.co.za

The Beijer International Institute of Ecological Economics
The Royal Swedish Academy of Sciences
Astrid@beijer.kva.se
Fax: 46-8152464

RANESA

The Environmental Economics and Policy Programm
Department of Agricultural Economics, University of Pretori
Nking@nsnper1.up.ac.za
Tel: 27-12-4204105 / 4203317 Fax: 27-12-420324

RESOURCE ACCOUNTING NETWORK
FOR
EASTERN AND SOUTHERN AFRICA

Funded by the Swedish International Development Agency (Sida)

Table of Contents

SUMMARY

The cooperative versus non-cooperative management of the South African west coast hake stock is explored using game theoretic modelling in conjunction with an age-structured model. The age-structured model is used to produce a physical flow account for input into national resource accounts. Between 1989 and 1998, the average catch of hake on the west coast was 92000 tons, most of which was harvested by the demersal trawl sector. The physical flow account indicates that the conservative re-building management strategy pursued for the fishery over the same time period mentioned above, has resulted in a 29% increase in the demersal trawl catch over the last decade.

We simulated the effects of alternative quota restrictions on two fishing sectors (the established demersal trawl fleet and the new longline sector) that compete for the rights to fish the stock. The results from the bio-economic analysis (which forms a basis for a monetary flow account as we calculate the Net Present Value of the stock) indicate that the greatest rent can be obtained by allocating a share of the total allowable catch (TAC) to longliners. This share that achieves the greatest benefits approximates the current TAC allocations to each sector under the present conservative management policy implemented by the management authority, assuming one takes into account the uncertainties inherit in a computational exercise like ours. This outcome implies that the current management initiatives by the government are such that they meet the objectives of the new Marine Living Resources Act. That is, the need to achieve optimal utilisation of resources is being adequately implemented.

The results of the game theoretic analysis provide an indication of why the current introduction of longlining may affect the government-industry cooperative management arrangements. A difference of R50 million will accrue to longliners

over the next thirty years if they engage in non-cooperative rather than cooperative strategies. The latter occurs under the assumption that the trawl sector reduces effort under a cooperative strategy. The results indicate that management policies, which ignore economic realities, could fail. However, a cooperative strategy is still a viable option for the trawl sector, because a difference of R1357 million can be obtained over the same time period if the trawl sector engages in cooperative behaviour.

These results are based on the assumption that benefits accrue to the quota holders under security of tenure allowing them to consider the long-term sustainability of the resource. Some form of security of tenure is still uncertain under the government's re-structuring program, although a number of new policies are now in place to help implement longer term rights. These policy initiatives should create a positive environment for all the stakeholders such that they can consider the long-term sustainable utilisation of the resource. Otherwise, rent will be forgone if the rules governing participation (i.e., rights) and the allocation of benefits for shared stocks are not well defined and constrained.

LIST OF TABLES

LIST OF FIGURES

ACKNOWLEDGEMENTS

Prof Rashid Hassan, Prof A Leiman and Dr G-M Lange are all acknowledged for their support and valuable advice. Dr Rob Tilney and Dr Rob Leslie (Marine and Coastal Management, Department of Environmental Affairs and Tourism) are both acknowledged for providing data on the Cape hake resource. The Resource Accounting Network for Eastern and Southern Africa (RANESA), the Swedish International Development Agency (SIDA) and the Beijer Institute (Sweden) are all gratefully acknowledged for providing funding for this project.

1. INTRODUCTION

1.1 Natural resource accounting and South African fisheries

The new Marine Living Resources Act (1998) has sustainable fisheries management as its first objective. Policy reforms are also underway to re-structure the industry in order to address the inequities of the past. The Act focuses on maximum utilization of marine resources for the benefit of all South Africans while also increasing foreign earnings. The development costs of this policy still have to be assessed along with both economic and social benefits. The construction of a set of Natural Resource Accounts (NRA) would represent a necessary step towards assessing whether the current resource utilization is sustainable under the new policy initiatives in South Africa.

South Africa's coastline is over 3 000km long and the nation has an Exclusive Economic Zone (EEZ) of approximately 1 million km^2 which contains a variety of fish species. The fishing industry is complex in terms of fishing sectors, processing capability, markets, capital investment, equipment and infrastructure. South Africa is a medium-sized fishing nation on global standards, landing between half a million and one million tons of fish annually from 1975 to 1991 (SFRI 1993). This catch generates foreign exchange and provides employment. At the national level the fishing industry comprises 0.5 per cent of the US$136.2 billion GDP[1]. However in the Western Cape, where the majority of fishing occurs, the industry represents 1.5 per cent of the local economy and employs more than 25 000 people. In 1994 the harvest for the entire South African fishing industry had an estimated annual wholesale value of US$390 million, to which the demersal and mid-water trawl contribute just over 50 per cent (Table 1, Stuttaford 1996). The bulk of the South African demersal catch comprise of Cape hakes (for example 62 per cent in 1991, Stuttaford 1993). Thus the two species of Cape hakes form the basis of the most important fishery in the country and therefore the subject of our study.

Table 1 The catches and economic value of South Africa's commercial fisheries in 1994 (from Stuttaford (1996) $US 1 = Rand SA 3.57 (exchange rate on 31.12.94)).

Sector	**Nominal Catch (t)**	**Wholesale Value – processed US$ millions**
Demersal and Midwater trawl*	188 842	201
Pelagic	315 545	81
Rock lobster	3 190	47
Linefisheries		
Tuna	4 069	6
Squid-jigging	6 442	19
Handline fishery	12 878	21
Abalone	613	15
TOTAL	**531579**	**390**

*Includes hake - the main species targeted which is reviewed in this case study.

There is a need to quantify the natural capital of fish stocks in economic terms and to consider South Africa's options for long term investment in natural capital versus stock depletion and ecosystem degradation. This can be assessed by calculating the net present value of future income streams under alternative harvesting methods and management policies. The potential outcomes of alternative policy options are particularly important to managers because the opportunity costs of providing fishers with alternative means of employment are often high.

Of particular interest is the application of bio-economic models to evaluate tradeoffs between alternative fishing methods using game theoretic methodology (see for

---

[1] The Economist, 2000.

example Sumaila 1997). The fisheries along with alternative harvesting methods must be included in an assessment of South Africa's marine living resources. The Resource Accounting Network for Eastern and Southern Africa (RANESA) is a regional network tasked with enhancing capacity in the development and use of NRAs in Southern Africa. Our aim was to carry out an analyses that would provide a crucial input for a NRA for the South African economy, namely an assessment of the value of South Africa's fishery resources. In a review of the application of NRA to various countries, Leefers and Castillo (1998) do not list any cases where fisheries are studied. Thus there is a need to include South African fisheries within a NRA.

Various methods have been proposed and applied for the integration of environmental concerns into economic indices (see Gilbert and Hafkamp 1986, El Serafy and Lutz 1989, Repetto *et al*. 1989, Hull 1993, Moffat 1995, Alfsen 1996, Bartelmus 1996, Daly 1996, Lai 1997, Nordhaus and Kokkelenberg 1999). Prudham and Lonergan (1993) provide a summary of the various techniques although there is a need for a more recent review. Natural resource accounting has also been applied to Southern African resources, for example, Crowards (1996) considered woodlands, soils and minerals in Zimbabwe. One method is to follow the United Nation's SEEA (System of Integrated Environmental and Economic Accounts)(United Nations, 1993) which emphasizes the compilation of physical and monetary accounts. Bloem and Weisman (1996) provide a critique of the SEEA approach. Lange (1998), in another example of a NRA assessment of resources in Southern Africa, used the SEEA methodology to consider the incorporation of Namibia's water resources in the national accounts.

Both the physical and monetary accounts rely on the compilation of stock and use accounts constructed for a benchmark year and all other years for which data are available. Economic data also needs to be collected to calculate the economic contribution of fish harvests to different sectors of the economy. Our goal is to analyse current harvest levels and policy using flow accounts of NRA. The natural capital of hake stocks, which contribute the greatest value to the wealth generated from the nations fish stocks, have to be quantified in economic terms and future options for long term investment in this capital have to be considered. The concept of managing fish stocks in a similar way as managing human-made capital is well established (see Munro 1992, Clark and Munro 1994). The alternative of negative investment due to poor management would result in depleted fish stocks and degradation of marine ecosystems. Depleted stocks would have negative effects on a country as a whole because a decrease in the net aggregate investment will result in a decrease in social welfare (Dasgupta and Mäler 1999). Thus it is essential that the net aggregate investment be quantified for natural capital such as a fish stocks.

The benefits of management can only be assessed by calculating the net present value of future income streams under alternative harvesting methods (trawl versus longline for the hake stock) and management policies. Thus the potential rent from the hake fishery under different configurations of trawl/longline catch levels must be calculated, providing vital input to future studies on rent capture and its distribution among different stakeholders. This will allow the management authorities to consider realistic policy alternatives that can then be evaluated in a multi-sectoral framework. Such a framework would take into account the full range of development objectives and the sectoral strategies for achieving alternative objectives. This would form the basis of an input of fisheries into a NRA. The NRA can then be linked to national accounts through the use of the same classification of economic activities as was undertaken by Lange (1998) for Namibia's water resources. The case study in this project will construct the physical and monetary accounts for the west coast deepwater hake fishery providing a model for future fisheries assessments in the region.

1.2 Aim of study

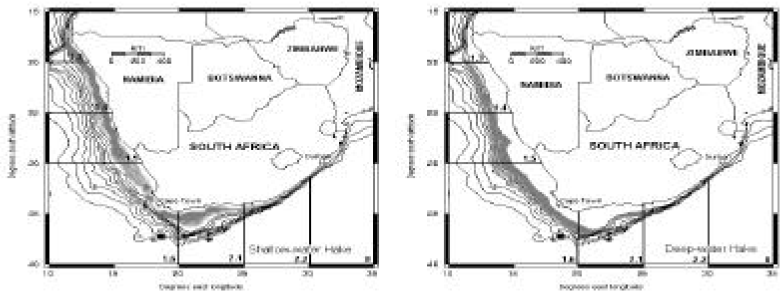
The aim of this study is firstly to undertake a bio-economic assessment of Cape hake on the west coast of South Africa and secondly to analyze potential outcomes under alternative management arrangements. Numerous requests have been made for the redistribution of quotas in South Africa in order to redress the imbalances of the past. The re-distribution of quota to newcomers and previously disadvantaged South Africans is occurring with the creation of new players, rather than via the elimination of existing quota holders. It is worth noting that up until now a bio-economic assessment, which considers both sectors (the demersal trawl and longline sector), has not been undertaken for this fishery. The research is important in that it will add a scientific perspective to the ongoing debate over the restructuring of the industry. Although the hake fishery has traditionally been a trawl-based fishery, the question that needs to be asked is whether the longline fishery will have positive or negative effects on the traditional fishery. More importantly, the question needs to be asked whether the longline fishery will provide greater economic benefits to the country. The specific questions addressed include (i) what are the short-term economic losses to the trawl fleet of an increase in the longline fleet, (ii) what mix of trawlers and longliners provides the greatest catch, and more importantly (iii) what mix provides the greatest economic benefits?

2. BACKGROUND: THE MANAGEMENT OF CAPE HAKES

The Cape hake or Stockfish (a popular name for hake in South Africa) is an important commercial demersal fish species. Its distribution extends along the entire western seaboard of South Africa from Cape Point to north of the border where it is also fished in Namibia. Hake are also found on the south-east coast on the Agulhas Bank. The Cape hake fishery is of considerable social and economic value to South Africa. Annual hake catches by the South African fishing fleet over the period 1982-1991 remained fairly constant, averaging 138 000 tons per year. Payne (1989) provides a detailed history of the hake fishery off southern Africa.

Reviews of the biology of this resource are provided by Botha (1980), Crawford *et al*. (1987), Payne (1989) and Payne and Punt (1992). Cape hakes consist of two morphologically similar hake species, *Merluccius capensis and M. paradoxus* (Van Eck 1969). Since it is not easy to distinguish visually between the two species only the total combined species catch is recorded. The distribution of each species is depth-dependent; *M. paradoxus* occurs in deep water while *M. capensis* is a shallow water species (Botha 1973) (Figure 1). The distribution areas of the two species overlap in intermediate waters where small *M. paradoxus* occur together with medium to large *M. capensis* individuals as the size of fish of each species tends to increase with depth (Botha 1973). Consequently the adults of the two species do not mix and the species maintain their integrity by spawning at different depths (Botha 1973).

Figure 1 The distribution of *Merluccius capensis* (Shallow-water Cape Hake) and *M. paradoxus* (Deep-water Cape Hake) off the coast of South Africa and Namibia. The ICSEAF divisions are also shown.

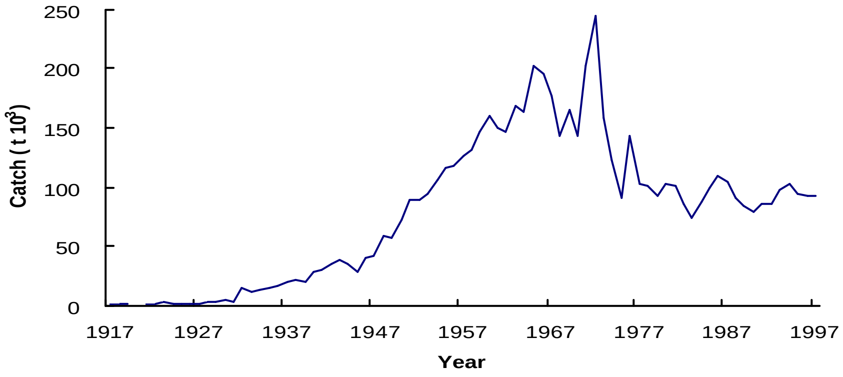


Earlier workers (for example Roux 1949) were convinced that there was some form of horizontal annual hake migration, but such conclusions were drawn on the erroneous premise that only one species existed. Van Eck (1969) later confirmed the presence of two hake species in local waters. There is a tendency for hake to move offshore into deeper water as they grow older and there appears to be some seasonal movement of adults inshore and offshore (Payne *et al.* 1989), but apart from that, there is no firm proof of extensive horizontal migration (Botha 1973, 1980).

2.1 Management of the fishery

Since the turn of the century Cape hakes have formed the basis of a substantial local trawl fishery. This fishery was initially based in Cape Town, but later (in the 1960s) became established at Saldanha. Only a thousand metric tons was caught in 1919, but catches steadily increased to 30 000 metric tons before the Second World War (Figure 2). Later catches of Cape hakes in the southern Benguela increased from 50 000 tons in 1950 to about 160 000 tons in 1960 (Crawford *et al.* 1987)(Figure 2). After 1962 Cape hakes also became a sought-after target for foreign trawlers from several countries. By 1972 the maximum catch of just over 1.1 million tons was reached (Payne 1989). The increasing fishing effort made a substantial impact on stock densities and catch rates decreased by 47 per cent between 1940 and 1966 and a further 50 per cent between 1966 and 1975 (Jones and Van Eck 1967).

Figure 2 The total catch from 1917 to 1997 in ICSEAF division 1.6 (see Figure 1, data from Leslie 1998).



The local fishery has traditionally confined its activities to the fishing grounds around Cape Town and to a lesser extent off the southern coast of South Africa. Foreign vessels concentrated in areas further north, off the coast of Namibia. The International Commission for the Southeast Atlantic Fisheries (ICSEAF) was established in 1972 to investigate and control the international fisheries for hake off South Africa and Namibia (Andrew and Butterworth 1987). Since 1978 total allowable catches (TACs) off South Africa were set to rebuild the stock, by applying an $f_{0.1}$ or an $f_{0.2}$ harvesting strategy. The fishery off South Africa has been managed exclusively by the nation since the declaration of a 200 nautical mile exclusive fishing zone in 1977. However the ICSEAF Scientific Advisory Council continued to consider assessments for the hake stocks in South African waters, and to allocate quotas for hake off Namibia until ICSEAF was dissolved in 1990 following the independence of Namibia. More recently effort has concentrated on the investigation of alternative management procedures for the Cape hake resource off the west coast of South Africa (see Punt 1991).

For management purposes ICSEAF divided the area under its management into Divisions. Off South Africa Division 1.6 corresponds to the west coast, and Divisions 2.1 and 2.2 correspond to the south coast (see Figure 1). In all four ICSEAF Divisions, catch per unit effort (CPUE) figures indicate a steady decline up to the late 1970s, when catch rates reached their lowest recorded levels. At that time a dynamic production model was introduced for managing the resource using CPUE data (Andrew and Butterworth 1987).

Although a global TAC is set for management purposes, the hake resource off South Africa has been divided into two stocks, and scientific TAC's are formulated for each stock, under the assumption that the stocks of hake off the south and west coasts are biologically isolated (Payne and Punt 1992). However Payne *et al.* (1987) suggests that there may be some interaction between the *M. paradoxus* stocks on the south and west coasts. Current scientific TAC recommendations for the South African hake fishery are based on a dynamic production model estimation procedure which utilizes catch, CPUE and survey biomass data (see Punt 1988, 1992).

2.2 The long-line versus trawl debate

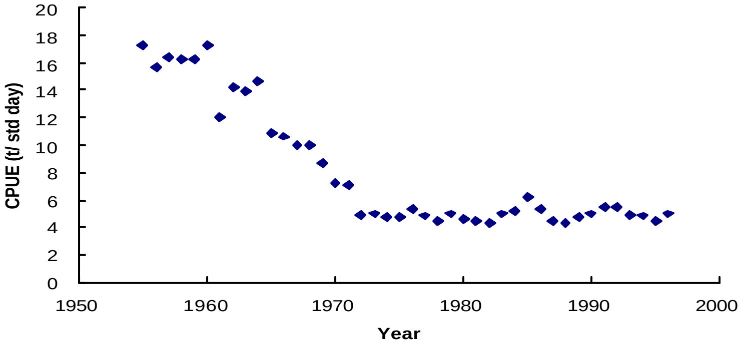
Successful trials on the capture of hake by longlines in 1983 led to a rush for concessions (42 in one year). The method resulted in high catch rates, was selective and could be employed on a rough substrate (Stander 1995). Realizing the potential of this new fishery, the authorities in May 1983 prohibited the capture of hake using the longline method (Stander 1995). During 1983 six experimental permits for longlining were issued (for 1500 t of hake) and despite the high catch of kingklip and the warnings from the Sea Fisheries Research Institute (SFRI, now Marine and Coastal Management), the authorities issued a further six permits to non-hake quota-holders in 1985. The longline operations were to

target hake, however Kingklip (the bycatch of the longline permits), were immediately targeted as the species of preference as they were worth four times the value of hake. Prices for landed kingklip were in the region of R8/kg in 1985.

By 1986 longline catches reached a peak of 10364 tons of which hake constituted a mere 16 per cent, the rest comprising mostly of kingklip (Stander 1995). From 1986 to 1990 the Minister, the Fisheries Advisory Council and Sea Fisheries attempted to formulate measures to satisfy conflicting interests. However by March 1990 it was clear that the kingklip resource was severely overfished. In June 1990 the Minister announced an end to all longlining. The six non-quota-holders were compensated by means of a hake quota of 240 tons each and have since regrouped into four companies (Stander 1995).

In 1993 a cooperative Longline Experiment was set up. The longline experiment involved a joint strategy between tuna and squid fishers (who were longlining), the established industry and government in order to evaluate the bio-economic value of longlining (Anon. 1995, Badenhorst 1995). The parties involved in the experiment were brought together in workshops to evaluate alternative strategies for data collection (see Fowkes and Sowman 1994). It is often suggested that longlining is potentially detrimental to the established trawl based industry as they target larger fish and thus threaten the large fecund females, reducing the spawning stock biomass (SSB) and thus threatening the long-term productivity of the stock (Anon. 1992, 1993). On the other hand the longline sector question the biological rationale for being precautionary with longlining even though kingklip were overfished as the trawl fleet target immature fish (65 per cent of the fish landed are less that 0.8kg). Preliminary assessments on both coasts, the west coast and south coast (Butterworth *et al*. 1992, Geromont *et al*. 1995, 1995b) indicate that a higher yield-per-recruit can be obtained by using longlines. These assessments were based on extensive research undertaken by Armstrong and Japp (1992) and Japp (1993, 1995a-e, 1996).

Figure 3 The hake CPUE from 1955 to 1997 in ICSEAF division 1.6 (see Figure 1, data from Leslie 1998; after the CPUE was standardized using a General Linear Model (GLM) taking into account changes in power factors).



The original trawl CPUE trend (i.e. before the application of a General Linear Model (GLM)) showed a 3 per cent increase over the last few years and this was thought to be due to the conservative policy of the $f_{0.1}$ and $f_{0.2}$ fishing strategies. After standardizing the relationship with the GLM by taking into account changes in power factors, the revised trawl CPUE over the last few years shows no significant change for the years (1972-1998, p=0.337)(Figure 3). Under a revised Operational Management Procedure (OMP) in November 1998, a fishing effort of $f_{0.075}$ has been chosen as the harvest rate for the stock.

3. METHODS

The surplus production model and *ad hoc* tuned VPA assessment methods currently used to provide the basis for scientific TAC recommendations for the Cape hake resource off South Africa provide rather different appraisals of the current status and productivity of this resource. These two methods are based on certain assumptions regarding recruitment, natural mortality and fishing selectivity. In this analysis the approach is to introduce the application of an age-structured model, which when using CPUE data provides similar results to the production model and the VPA assessments depending on alternative assumptions regarding the selectivity of gear.

3.1 Age-structured models and yield simulation

An age-structured model is an assessment technique which can take account of the age-structured nature of fish populations, but does not necessarily require estimates of the age-composition of the catches (although the option to incorporate catch-at-age data exists) (Hilborn 1990, Punt 1993). The model can be formulated such that it is able to predict changes in population size and yield under different patterns of selectivity. This approach involves constructing a deterministic age-structured population model which assumes that recruitment is deterministically related to spawner stock biomass (SSB). These age-structured models include numbers of individuals at each age, age-specific mass, age-specific fishing selectivity, as well as natural mortality rates and stock-recruitment parameters and yield. Generally age-structured models can be written in a variety of different ways. The choices that must be made are whether the fishing and natural mortalities are assumed to be continuous processes acting simultaneously, or separate discrete time events. The model used here is a discrete time model based on Hilborn (1990). The general age-structured model can be written simply as:

$$N_{y+1,a+1} = N_{y,a}\, e^{-(Ma + Sa\ Fy)} \qquad \text{(E.1)}$$

where

$N_{y,a}$ is the number of fish of age a at the start of year y,

M_a is the rate of natural mortality on the fish of age class a,

S_a is the selectivity of the fishery on fish aged a years ($0 < S_a < 1$),

F_y is the fishing mortality for fully vulnerable individuals in year y, *i.e.* fish with $S_a = 1$ (the year effect for the fishing mortality).

To take age effects into account fishing mortality-at-age ($F_{y,a}$) is separated into an age-component which is common to all years (age-specific selectivity - S_a) and a year-component which is common to all ages within a particular year (year effect of fishing mortality - F_y). This assumption is justifiable if the distribution of fish and fishing vessels does not vary substantially from one year to the next. Two scenarios in which the separability assumption would not be justified, and which might be pertinent to any fishery (Punt 1991). The separability assumption is based on the following relationship:

$$F_{y,a} = F_y\, S_a \qquad \text{(E.2)}$$

where

$F_{y,a}$ is the instantaneous rate of fishing mortality on fish aged a during year y,

The spawning stock biomass SBB_y can be calculated as:

$$SSB_y = \sum_{a=m}^{Max} N_{y,a}\, W_a$$

(E.3)

where

SSB_y is the spawning biomass at the beginning of the year y,

W_a is the mass-at-age for a fish

m is the age at sexual maturity (assumed to be 5 years)

It is assumed further that there is a relationship between the spawning biomass SSB_y in one year, and the average recruitment in the following year (Beverton and Holt 1957):

$$N_{y+1,1} = (?\ SSB_y) / (SSB_y + ?\ )^? \qquad \text{(E.4)}$$

where

?, ? are the stock-recruitment relationship parameters.

Equations (E.1) - (E.4) define the dynamics of both numbers-at-age and biomass-at-age. It is possible to relate the model to observed data, however additional relationships need to be defined. It is assumed that the available indices of population abundance are proportional to stock biomass (where the abundance index is either CPUE or survey biomass). For the age-structured population model the equation for model-predicted catch (or sustainable yield if F is held constant) is:

$$C_y = \sum_{a=1}^{Max} W_a - S_a F_y\ N_{y,a}\, (1 - e^{-(Ma + Sa\ Fy)})/(M_a + S_a F_y) \qquad \text{(E.5)}$$

3.1a Life-history data utilized

Annual recorded trawl catch and trawl CPUE data for the South African west coast hake stock are shown in Figure 2 and Figure 3 respectively. The estimated total annual landed hake catch from the west coast is available (that is published) for the period 1917 to 1996 and landed catch by fishing method for 1983 to 1996 (Leslie 1998). Cape hakes consist of two morphologically similar hake species, *Merluccius capensis and M. paradoxus* (Van Eck 1969). Since it is not easy to distinguish visually between the two species only the total combined species catch is recorded thus the model is not single-species. Although Cape hake in Division 1.6 have been fished since the turn of the century, comprehensive trawl CPUE are only available from 1955. The catch statistics are usually reported in tonnes landed weight. Fish are headed and gutted before being weighed and therefore catch figures were converted to tonnes whole (nominal) weight by multiplying by a factor of 1.46 (Chalmers 1976). Nominal catches prior to 1972 were increased by 39 per cent to account for discarding of small hake (Andrew 1986). The collection of otoliths for ageing purposes and catch-length frequency data permits the breakdown of the total catch-by-mass into catch-at-age estimates. Length frequency data also exist for the years 1964 to 1977 for the west coast. In principle these data can be used to estimate catch-at-age for these years.

Although survey biomass data are available from 1983, they are not utilized here. Punt (1993) incorporated survey biomass data in his age-structured production model assessments and found in his sensitivity tests that the results scarcely changed when survey biomass data were not taken into account. Andrew *et al.* (1989) incorporated biomass survey data into their assessment and found that fits to the relative indices of survey biomass and CPUE data hardly changed from fits to the CPUE data alone. Although the biomass estimates have fluctuated over the period since 1983, they show no significant trend.

3.1.2 Estimation of parameters

3.1.2.1 Input parameters

Four age-specific parameters are needed before the population can be simulated. These include selectivity-at-age (S_a), mass-at-age (W_a), and mortality-at-age (M_a). The remaining parameter is age-at-maturity. The estimates of selectivity-at-age, mass-at-age and age-at-maturity were obtained from other sources. The parameter values for the logistic selectivity function are based on the analysis of selectivity-at-age conducted by Punt (1991). The values for the parameters related to growth and maturation were taken from Punt and Leslie (1991). The natural mortality-at-age was assumed to be constant over

the age classes considered. There are rarely any data to justify the assumption that mortality is age-specific and it is normally assumed to be the same regardless of age. In must be borne in mind that the hake size mix in the population is dynamic and affected by the survival of the different age classes. As Botha (1980) pointed out enhanced survival of both species to a large size will increase the rate of cannibalism on younger age classes. However increased fishing pressure on large hake will correspondingly increase the survival of younger age classes. Therefore it would be important to consider the effects of cannibalism on the age-specific mortality as well, however the paucity of data precludes such a study.

3.1.2.2 Selectivity-at-age

The selectivity function used in the "base case" model is a logistic curve which is assumed to be time invariant. The paucity of data on the selectivity of trawl gear changes over time preclude estimation of the extra parameters that would be required to reflect changes over time. The model used is:

$$S_a = 1/(1+ e^{((-a - A_c)/?)}) \qquad \text{(E.6)}$$

where

S_a	is the selectivity of the trawl gear on fish of age a,
A_c	is the age-at-50%-selectivity,
?	is a "steepness" parameter for the selectivity curve.

The values A_c = 2yr and ? ≟ 0.5 yr^{-1} used for the model are based on an analysis by Punt (1991). However to investigate the effect of decreasing selectivity-at-age for older fish the following selectivity function was used:

$$S_a = 1/(1+ e^{((-a - A_c)/?)}) \text{ for } a<a_m \qquad \text{(E.7)}$$

$S_a = e^{(-?\ (a-a_m))}$ for a>or = a_m (E.8)

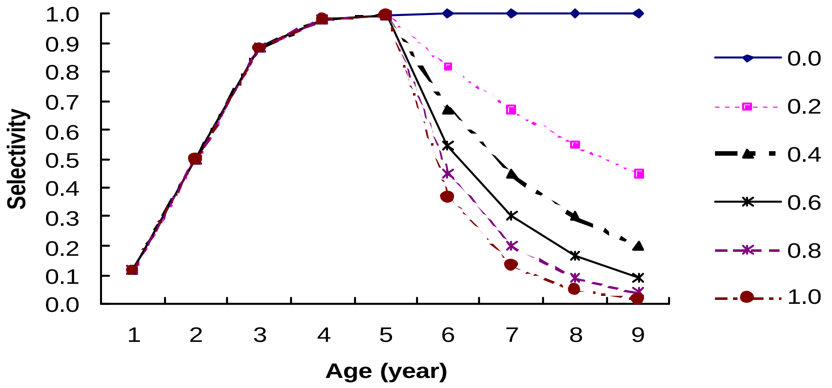
where

a_m is the age at which selectivity reaches its maximum value – after this age selectivity-at-age decreases and,

? ? is the exponentially decreasing selectivity coefficient at older ages.

The values for the parameters ? and a_m were chosen to be 0.1 and 5yr, respectively (Figure 4) for hake targeted by trawlers.

Figure 4 Selectivity versus age relationship for the trawl gear showing the effect of increasing ? .



The values A_c = 5yr and d = 0.5 yr^{-1} were used for the longline selectivity function (same as E.7) in the model. These parameters were estimated from the catch-at-age data for longline caught hake on the west coast for 1994-1996 (Leslie 1998).

3.1.2.3 Mass-at-age

Growth parameters were obtained from Punt and Leslie (1991). The length-weight relationship was obtained from Punt and Leslie (1991). The relationship between mass and age is calculated from the following function:

$W_a = A\ (Ly(1-e^{-\ KP(a\ -\ TN)}))^{b}$ (E.9)

(that is a Von Bertalanffy age-length relationship imbedded in a standard mass-length relationship)

where

W_a is the mass-at-age for a fish aged exactly a-1,

Ly is the asymptotic length of fish in cm,

KP is the rate at which length approaches Ly - the growth rate parameter and,

TN is the age at zero growth and,

A = 0.0055, Ly = 230.3, b = 3.084, KP = 0.046, TN = -0.825

The values for the parameters related to growth and mass-at-length were selected on the basis of the results of Punt and Leslie (1991). Punt and Leslie (1991) found that the difference between the two species for both maturation and growth is not particularly marked and that it is justifiable to use one set of growth/maturity parameter values when performing assessments.

3.1.2.4 Mortality-at-age

For most estimation procedures mortality is assumed to be constant, either M= 0.3 yr^{-1} or M= 0.5yr^{-1}. In order to be consistent with previous assessments of the resource (for example Andrew 1986), a value of M= 0.3 yr^{-1} was chosen for the assessments.

3.2.1 Parameters estimated by the model

The parameters which are obtained by fitting the model to the available data are the catchability coefficient (q), the relationship between the biomass and index of abundance (CPUE) and the two stock-recruitment parameters α and b. The first step in the regression is to obtain a set of initial age-class numbers, $N_{y,1}$. This is done by setting the initial age-distribution equal to that of the deterministic unexploited equilibrium (denoted by *) level for the stock (*i.e.* the age-structure corresponding to $F_y = 0$, for y<1917, see Punt 1990), therefore:

$$N^*_{y,a} = R^*_1 \, e^{-\sum_{r=1}^{a-1} M_r} \qquad \text{(E.10)}$$

and

$$SB^*_1 = \sum_{a=m}^{Max} N^*_{y,a} \, W_a \qquad \text{(E.11)}$$

where

$N^*_{y,a}$ is the equilibrium number of fish of age a at the start of year y

R^*_1 is the average equilibrium recruitment

SB^*_1 is the spawning biomass at equilibrium.

By substituting equation (E.10) into equation (E.11) it is possible to obtain a relationship for spawning biomass at equilibrium (SB^*_1) in terms of average equilibrium recruitment (R^*_1):

$$SB^*_1 = R^*_1 \sum_{a=m}^{Max} W_a e^{-\sum_{r=1}^{a-1} M_r} \qquad \text{(E.12)}$$

setting

$$\gamma = \sum_{a=m}^{Max} W_a e^{-\sum_{r=1}^{a-1} M_r} \qquad \text{(E.13)}$$

gives

$$R^*_1 = SB^*_1 / \gamma \qquad \text{(E.14)}$$

For the Ricker stock-recruitment relationship:

$$R^*_1 = a \, SB^*_y \, e^{-b \, SB^*_y} \qquad \text{(E.15)}$$

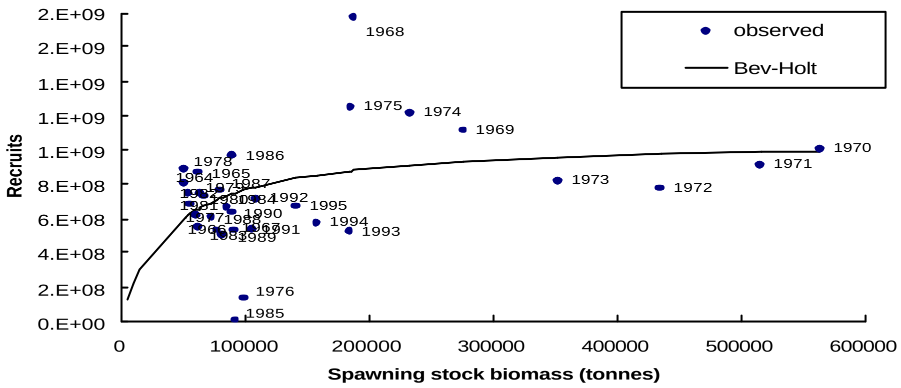
Equations (E.14) and (E.15) can be solved for the average equilibrium recruitment (R^*_1) and the equilibrium spawning biomass (SB^*_1). The result is:

$$R^*_1 = ln\,(a\,\gamma)/(b\,\gamma) \qquad \text{(E.16)}$$

A similar derivation can be done for the Beverton-Holt stock-recruitment (see Figure 5). Relationship giving the following relationship for the average equilibrium recruitment (R^*_1) level:

$$R^*_1 = = (a\,\gamma - b)/(\gamma) \qquad \text{(E.17)}$$

Figure 5 A typical fit of the Beverton-Holt stock recruitment relationship to the observed data.



Equation (E.16) and (E.17) can be substituted into equation (E.10) to compute the initial conditions for both stock-recruitment relationships:

$$N_{1917,a} = R^*_1 \, e^{-\sum_{r=1}^{a-1} M_r} \qquad \text{(E.18)}$$

The assumption that the hake stock was at equilibrium at its carrying capacity at the start of 1917 would seem to be realistic, because catches prior to 1917 were negligible.

3.1c The regression approach

Once the input parameters and the necessary starting conditions specified, an exploitable biomass sequence can be calculated and compared to the observed index of exploitable biomass (*i.e.* CPUE). The simulated and observed indices of abundance (CPUE) are incorporated into an objective function of the form:

$$SS = \sum_{y=1955}^{1997} [\ln (q\, B^E_y) - \ln (C_y / E_y)]^2 \qquad \text{(E.19)}$$

The use off logarithms in the objective function is based on the assumption that the dominant noise in the model is in term C_y / E_y, that is the choice of the error in the model is "observational error", and that this noise may arise from catchability fluctuations. Changing environmental factors, seasonal migration and behavioral/distributional changes tend to produce inter-annual catchability fluctuations. One would expect catchability to be influenced by a large number of these factors, each of which may well be independent and have a multiplicative effect. The central limit theorem implies that the sum of the logarithms of the magnitudes of these factors approaches a normal distribution, and therefore taking logarithms is the most appropriate transformation to use in the objective function.

The minimization procedure AMOEBA (Numerical Methods, Cambridge 1988) was used to find the parameter values which would provide the best fit. In order to be consistent with previous applications (Hutton 1992) of this method the Beverton-Holt form of the stock-recruitment relationship was used. In the model, *q* and the parameters of the stock-recruitment relationship (*a* and *b* for the Beverton-Holt relationship) were estimated.

3.2 The bio-economic model

3.2.1 Calculating the NPV

Those in decision-making positions often require that analyses are translated directly into economic values. Estimates of yield are obtained from the biological model. Prices and costs per unit weight of fish landed are applied to the estimates of yield in order to obtain profit (rent) under alternative scenarios. The total long term benefits (that is, the sum of predicted rent per year over the time horizon of the analysis) under alternative scenarios of resource exploitation can be calculated by computing the Net Present Value (NPV) of the stream of benefits over time. This would provide as with the equivalent of a monetary flow account as here we assume that cost is the sum of all the costs to the producer (for example intermediate consumption, compensation to employees, depreciation of capital, return on investment). The NPV depends on the discount rate (δ), which captures both society's time preference for consumption and the opportunity cost of capital. Total discounted net present value (NPV, that is the long term benefits) can be calculated over a set period of time, t=1..T, where T=30 is the terminal year of the analysis):

where:

$$NPV = \sum_{t=0}^{T} \left[\frac{1}{(1+d)^{t}} (PY_{t} - CY_{t}) \right] \tag{E.20}$$

δ = discount rate

t = time

P = landing price per ton for each sector

Y_t = total yield (tons) landed at time t,

C = cost per ton for gear for each sector

The discount rate used in this study is δ=0.1 (10 per cent) which is high on a global scale. However it is satisfactory for this study because in South Africa the inflation rate on basic food items is in the region of 10 per cent and the prime interest rate on money borrowed is in the region of 20 per cent, providing an estimate of 10 per cent for the

discount rate used in this study. This is in agreement with the 10 per cent discount rate used by the World Bank for evaluating the cost and benefits of projects located in developing countries.

3.2.2 A brief review of the literature

Much of the literature focussing on fisheries bio-economic models are analytical in which equilibrium solutions are determined and discussed. Many solutions of dynamic bio-economic models have been presented in the literature (see Clark 1990, Clark and Munro 1982, 1994, Munro 1981, 1992, 1998, Munro and Scott 1985). These studies present dynamic optimization problems of the type given in equation E.20 constrained by the biological model of the resource stock. The results of these studies confirm what has become known as the 'modified Golden Rule' of resource or capital accumulation, as it provides a rule for determining the extent to which society should invest in a resource. Usually the optimal biomass lies between the biomass at bionomic equilibrium (no rent generated) and the biomass at maximum sustainable yield. The path taken to the optimal solution is complex (see Clark *et al*. 1979). The policy implications of the modified Golden Rule are such that it is only rational for a participant in a fishery to invest in the future if the benefits of the investment accrue to them. Also the gains they make should at least equal the gains from alternative investments. It is difficult to include age of fish in these analytical models thus the approach taken here is to use a simulation model, which is forward projecting[2].

3.2.3 Economic data utilized

---

[2] Saville (1997) considered the west and south coast hake fisheries, but could not include both the trawl and the longline sectors as the form of his model was not age-structured.

Obtaining cost data and particularly the short run cost data (marginal and average) can be problematic. In South Africa it is difficult to obtain cost relationships considering the paucity of information from the demersal trawl sector, since the various companies make every effort to remain competitive. Companies do not readily publish their cost information (Saville 1997). It is easier to obtain cost data from the longline sector as they have made numerous submissions to the government requesting larger quota shares based on economic factors. In practice it is possible to present short-run cost data as the fixed costs plus variable costs of vessels and obtain short-run fleet cost data by aggregating short-run vessel cost data (see Doll 1988). Based on the latter method, Sumaila (1995) presents a cost function for each vessel, which even though for most practical purposes is linear in effort includes a parameter (b=0.01). The introduction of this parameter in the cost function ensures strict concavity of individual profits as a function of individual effort. However in fisheries models a special case exists as the long run fleet cost data is required for simulations of alternative harvest strategies (Doll 1988).

One of the first attempts, to obtain reliable economic data for both the longline and trawl sector, was made during the Longline Experiment which began in 1993, when 3000t were allocated to the longliners. Data were collected in 1995, 1996 and 1997 (that is three consecutive years).

The economic data from the Longline Experiment consisted of:

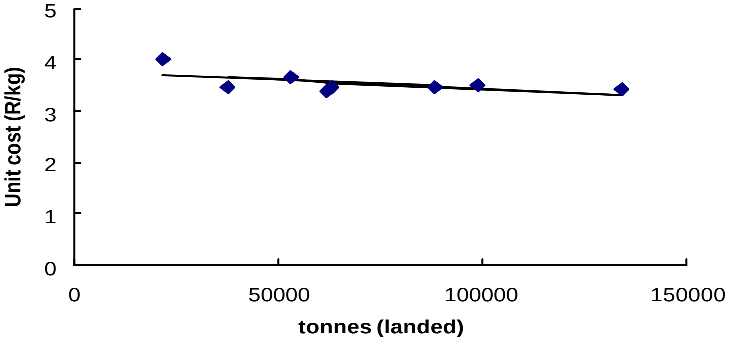
- Sales price per kilogram hake caught;
- Landing cost per kilogram hake caught;
- Total cost per kilogram hake caught;
- Net income before interest and tax per kilogram hake caught;
- Return before interest & taxation on capital investment.

However the reliability of the data collected during the Longline Experiment (see Anon 1998) can be questioned because of the high confidence intervals. At that time (average data for 1995-1997), the cost for landing a kilogram of hake by the longline fleet was R5.75 and the cost for landing a kg. of hake by the trawl fleet was R5.00 (Anon 1998). The average price paid for longline landings was R8.50 R/kg and the price paid for trawl landings was R6.75 R/kg (Anon 1998).

Short-run cost data

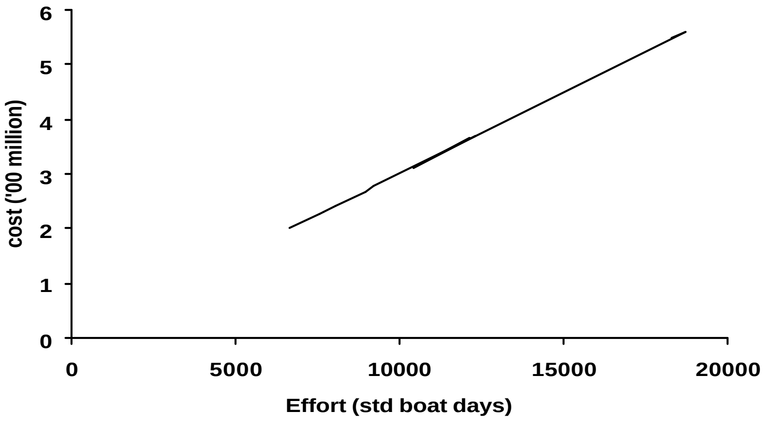
The assumption that short-run marginal cost is equal to the average cost for longlining is based on the data presented in Figure 6. Figure 6 shows short-run unit cost versus production for one of the most efficient fishing firms operating longline vessels in 1999. The slope of the unit cost versus production relationship (in Figure 6) shows no significant change (p=0.12) indicating that for our purposes it can be assumed that marginal cost is equal to average cost. As with Saville (1997) we had to assume that the same relationship holds for trawling in the short-run.

Figure 6 The relationship between unit cost and production (tonnes landed) for a fishing firm harvesting hake with longliners in 1999.



Obtaining data from the trawl sector is always problematic because of the extremely low level of disclosure by the industry. However we were provided with an estimate for the cost of fishing effort from the industry (from one the two largest companies) for 2000. It costs on average R30000 for a *std boat day* of trawl fishing effort. We can use this estimate to obtain total cost versus exerted fishing effort for a range of trawl fishing effort levels (Figure 7), however this computed relationship is more appropriate for the analysis of the long-run cost data as it provides us with an estimate of total cost over a wide range of effort levels. A wide range of effort levels would only be observed over the long-run in a fishery.

Figure 7 The relationship between cost and trawl fishing effort based on the assumption that it costs on average R30000 for a std boat day of trawl fishing effort in 2000.



Long-run cost data

As already stated, in fisheries models, it is important to apply long run fleet cost data (Doll 1988). We are in effect considering potentially very large wide-ranging changes in effort between the two sectors over a considerable time (we calculate the NPV over a 30 year period), when we simulate the effects of alternative harvest strategies. Therefore we need a relationship between cost and fishing effort in *t/std day* as input into the model for the long run (for each sector that is trawl and longline)(or cost versus fishing mortality as we have estimated the catchability coefficient). We believe it is reasonable to assume that in the long run, the unit cost for both sectors is going to increase for very high effort levels (or fishing mortality rates) as CPUE decreases and *vice versa*. The trawl cost data we used are based on that presented in RAU (2000), where the average landed unit cost for trawling is R5.00/kg of hake landed (for 2000). For longlining we use a value of R5.00/kg of hake landed as the unit cost. We assume the unit cost presented in Figure 6 is an under-estimate for 2000 (at R4 per kg landed), as it is data collected from what is claimed to be the most efficient longline fishing firm. In addition the data presented in Figure 6 reflects the situation in 1999 and with the high rate of inflation it is reasonable to assume that in 2000 the value is greater.

The most important part of this exercise is then to equate this cost data to the current effort levels for each sector and then make some assumptions about long-run cost versus fishing effort (we assume it is linear). For example the current fishing effort levels in the trawl fleet are such that Fy[3] = 0.3 year^{-1} (and at this level, cost = R5/kg of hake landed). Therefore if we assume that cost is equal to zero when there is no fishing (that is effort equals zero), we can obtain a linear relationship between these two effort levels such that:

Trawl cost (per kg landed) = 16.667 Fy(trawl) (E.21)

---

[3] See Equation E.2 for a definition of Fy.

Note that in this case we relate cost to fishing mortality, but as stated before fishing mortality is correlated with fishing effort if we assume *q* is constant. Furthermore for longlining the same exercise can be carried out. The current fishing effort levels are such that Fy = 0.05 year^{-1} for longline caught hake (and cost is equal to R5/kg of hake landed). Thus using the same arguments as presented above we obtain a relationship such that:

Longline cost (per kg landed) = 100 Fy(longline) (E.22)

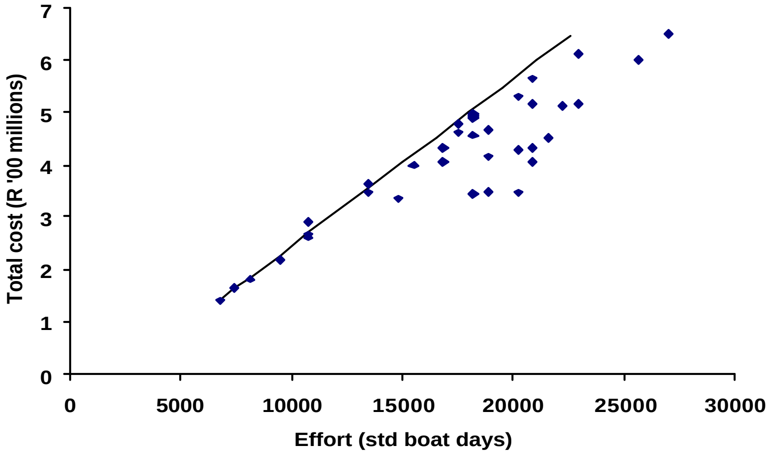
This does not directly imply that the cost of longlining is greater than trawling as Fy (trawl) is not equal to Fy (longline), because of the large difference in the selectivity of the gear. In fact, with the same Fy the trawl fleet lands more hake. Hence the cost of fishing effort in the longline fleet is less than fishing effort in the trawl fleet for the same Fy, remembering that the relationship between Fy and fishing effort for each fleet is not the same.

The final process in this procedure is to verify whether the above assumptions and parameter estimates provide us with the long-run fleet cost data, that is, total cost versus fishing effort. The total cost versus fishing effort is computed by multiplying the unit cost at a particular level of Fy by the yield obtainable at Fy (in this case for the trawl fleet).

Since, we assume *q* is constant and fishing effort is equal to Fy/*q*, we can plot the resultant total cost versus trawl effort (a function which is a by-product of the parameter estimates, the various stated assumptions and the dynamics of the model). The relationship is shown in Figure 8. It is reassuring to note that the relationship in Figure 8 (especially the fitted curve to values of effort < 15000 *std boat days*) approximates the other method of estimating the total cost versus trawl fishing effort shown in Figure 7 which was obtained from the industry[4].

Remember: the method used to obtain the relationship in Figure 8 relied on obtaining an estimate of unit cost and equating this value to current effort levels, formulating from this equation (E.21) and then multiplying the unit cost at a particular level of effort by the yield obtainable at this effort level. Whereas the function represented in Figure 7 is based on an estimate obtained from the industry, where they estimate that it costs on average R30000 for a *std boat day* of trawl fishing effort

Figure 8 The relationship between total cost and fishing effort for the trawl fleet. The solid line is obtained from a fit to lower effort levels. At higher effort levels total cost begins to decrease as the fishery approaches unsustainable levels and yield decreases.



---

[4] The functions in Figure 7 and Figure 8 have approximately the same slope and intercept. The differences are small considering the fact that these are estimates of aggregated data for a whole fleet.

It is pertinent to observe that for high effort levels (> 15000t per std boat day), which are not sustainable in the long term, the total cost values are lower than the assumed linear relationship which exists at low effort levels (< 15000 *std boat days*)(Figure 8). The reason is because at high effort levels the stock is being over-exploited at non-sustainable levels and yield is decreasing. A similar relationship between total cost and effort is assumed to exist for the longline fleet in our model as we have made similar assumptions with regard to all the functions, although the parameters and the values for the total costs differ.

Price data

Constant year 2000 prices were assumed when we project forward and calculate the NPV. The price data for each sector were obtained from RAU (2000). The price paid for trawl caught hake is R10/kg (wholesale). For longline caught hake the price is R30/kg (wholesale) when the market (in Spain) is not affected by imports of hake from other regions like South America. For example in July 2000 the price fell to very low levels and at one stage it was not worth exporting longline caught hake (that is for export hake the price was R0/kg). Therefore, in this model we use a price of R15/kg for longline hake, as this price approximates the R14/kg estimate for average landed price in South Africa (RAU 2000).

4. PREDICTING GAME THEORETIC OUTCOMES

Game theoretic modelling allows for the analysis of strategic interaction between agents (Osborne and Ruberstein 1994). As more than one agent typically has property rights to fisheries, game theoretic-modelling has been used to study non-cooperative and co-operative outcomes between agents within alternative fisheries management systems and property rights regimes (Ostrom *et al*. 1997). A review of game-theoretic models of fishing has been undertaken by Sumaila (1999) who notes that only a few attempts have been made to develop empirical game theoretic model of fisheries[5].

4.1 Using non-cooperative game theory

In many fisheries specific rules for allocation of the TAC do not exist for scarce resources, thus fishing units compete for access. The outcome of this competition is often negative leading to overfishing, overcapitalization, rent dissipation and conflict between interest groups, whose objective is to maximize own private benefits without due regard to the consequences of their actions on the payoffs of other players. Non-cooperative game theory (Nash 1951) allows us to consider the equilibrium outcomes of this competition.

Cooperative strategies are used interchangeably with co-operative management throughout this paper. This is realistic considering that co-operative management is only possible if participants are willing to engage in binding agreements implying they will behave in a cooperative fashion. Fishers will not enter agreements or obey regulations if the benefits of non-cooperation they receive are much greater than benefits of cooperation.

---

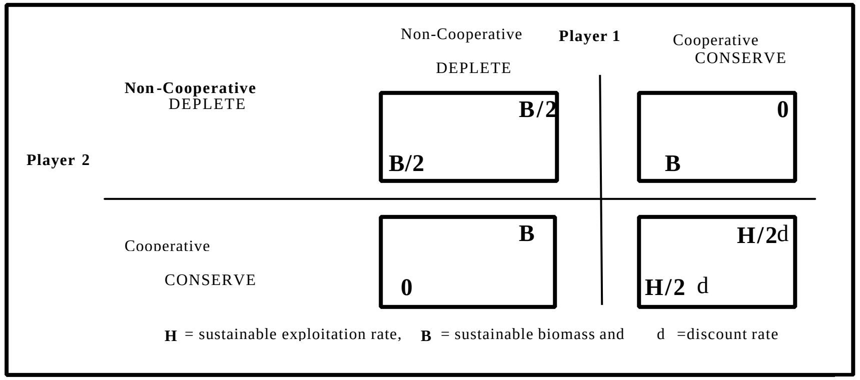
[5] Game theory has been applied to virtually all areas of economics and there is an increase in the number of studies (see references in Sumaila 1999). The contributions in Weintraub (1992) consider the history of game theory based on the classic work of von Neumann and Morgenstern (1944).

The aim of this study is to isolate the negative effects of non-cooperative strategies. This follows from the argument presented by Nash (1951, page 295): "The writer has developed a dynamical approach to the study of co-operative games based upon a reduction to non-cooperative form". The approach is thus similar to that applied in Sumalia (1995)[6].

Thus the approach of this paper is to assume that binding agreements are not feasible at this stage[7]. For example in South Africa various interests are in a real competitive situation for rights to the resource. The aim is to isolate the negative effects of non-cooperation (for example biological) and evaluate whether there are economic incentives for non-cooperation or not. This method is presented in Clark (1981, 1990) and for the sake of simplicity the computation is open-loop. Clark's (1981) terminology of ‘*deplete = non-cooperative*’ and ‘*not-deplete = co-operative*’ is used in this paper. The loss in potential rent to the government needs to be quantified assuming the government does not facilitate binding agreements. It is postulated that in this situation the government is not maximizing total benefits.

Within a non-cooperative game theoretic modelling approach, as in Sumaila (1995), where he uses an algorithm to find a solution, the benefits to each player can be generated. Under these conditions it is possible to compute the Nash equilibrium, which is the outcome when each player seeks to maximize on their private own payoffs, given the supposed actions of the others (Kreps 1990). In this paper we consider the effects of non-cooperative behaviour and therefore compute the difference in the outcomes between potential co-operative strategies and existing non-cooperative strategies (defined in each case depending on the status of the stock). In this case the payoffs to each player, as well as the total payoffs, are revealed. Thus it is possible to generate the total NPV of economic rent and estimate the maximum value (graphically in this case as the model is not of an analytical form as in Sumaila 1995).

Figure 9 The theoretical outcomes of a two player model as described by Clark (1990 and presented in OECD 1997). In each of the four scenarios above, the predicted benefits to Player 1 appear in the top right-hand corner and the predicted benefits to Player 2 appear in the bottom left-hand corner.



		Player 1 Non-Cooperative DEPLETE	**Player 1** Cooperative CONSERVE
Player 2	**Non-Cooperative** DEPLETE	**B/2** **B/2**	**0** **B**
	Cooperative CONSERVE	**B** **0**	**H/2**d **H/2** d

H = sustainable exploitation rate, **B** = sustainable biomass and d =discount rate

In the theoretical model, the assumption is that if the players in the game cooperate they will conserve and if they display non-cooperative behaviour they will follow a depletion strategy. Thus Figure 9 is adapted from Clark (1990, presented in OECD 1997). It is simplified from Clark’s (1990, presented in OECD 1997) two strategies of “conserve” or “deplete”. Furthermore based on Clark’s analysis, the OECD (1997) presents

---

[6] Hart (1998) considers the characteristics required for fishers to cooperate in the south Devon inshore fishery after reflecting on the ‘Prisoner’s Dilemma’. (as named by Albert Tucker in an unpublished paper - see references in Rasmusen 1995).

[7] Thus the aim is not to apply a cooperative game theoretic analysis as in other studies which assume the establishment of binding agreements is feasible (see Amstrong and Flaaten 1991, Kaitala and Munro 1993, Lewis and Cowens 1982, Munro 1979, 1987, 1990, 1992, 1994, 1996, Sumaila 1997, Yeto *et al*. 1997).

two cases: (1) where the discount rate (δ) is large and larger payoffs are obtained from depletion or not cooperating even if others do or (2) there is an incentive to cooperate and conserve (the discount rates are low and there are only a few players). However if the number of players (N) is large then each one receives a payoff of $H/\delta*N$. A "cheater" then receives a much larger share of B, than if he/she cooperates. Thus there are huge incentives to cheat as the number of players becomes large.

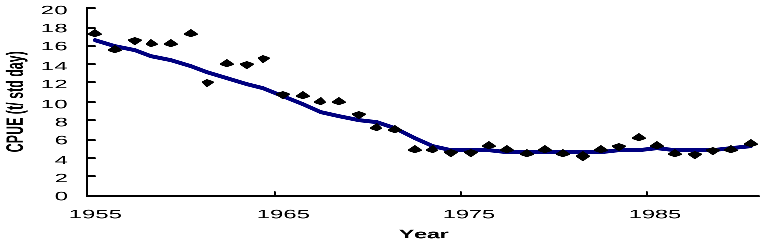
We assume that fishing companies that target hake will not enter agreements if the benefits of non cooperation to them are greater than the benefits to them from cooperation. The assumptions are that under the current re-structuring, the assumed non-cooperative strategy by the trawl sector will be to maintain fishing effort at its current levels (F= 0.3 year^{-1}), and the assumed cooperative strategy will be to reduce fishing effort (F = 0.2 year^{-1}). In 1998 after extensive negotiations the trawl sector accepted a reduction in their quota of 8000 t (which equates approximately to the latter effort reductions, that is F is reduced by 0.05 year^{-1}). For the Longline sector the non-cooperative strategy will be to increase F beyond their current quota limits (for example, F= 0.08 year^{-1}), whereas a cooperative strategy will be to maintain their effort at the level required to meet their current quota (which equates approximately to the longline sector effort being F = 0.05 year^{-1}). It should be noted that over the last five years participants have made numerous requests for an increase in their share of the total TAC.

5. RESULTS

5.1 Physical flow accounts: the biological model results

An age-structured production model (observed CPUE data were fitted) was constructed to simulate changes in F for trawlers and longliners. The CPUE derived from the model versus observed CPUE is shown in Figure 10.

Figure 10 The fitted age-structured model predicted catch-per-unit effort (solid line) to the CPUE data (◆). The model is tuned to observed trawl catches (1917-1997) and observed longline catches (1983-1990 and 1994-1997).



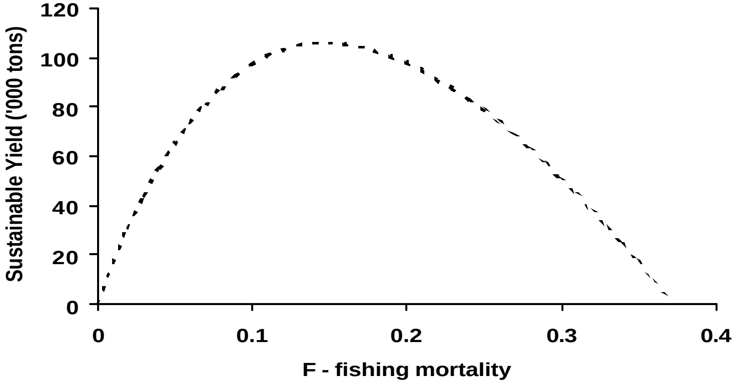
The estimates for MSY, B_{MSY} and B(1996)/K and K (the pre-exploited biomass) are shown in Table 2. In addition the values of the estimated parameters α, β and q are also shown in Table 2. The estimates for MSY are lower than those obtained by Punt (1993) however his analysis was based on the CPUE trend before it was modified by the GLM. The estimates of the current status of the stock (i.e the current biomass as a proportion of the unexploited biomass, B(1997)/K) indicate that the stock is fully exploited as this proportion is approximately equal to 20 per cent.

Table 2 Estimates for MSY, B_{MSY} and B(1997)/K and K (the pre-exploited biomass). The values of the estimated parameters α, β and q are also shown. Biomass units are in '000 tonnes.

Parameter	**Estimate**
MSY	105.65
B_{MSY}	1021.79
B(1997)/K	0.2081
K	1917.60
α	1.34×10^{9}
β	6.36×10^{11}
q	1.11×10^{-11}

The sustainable yield versus fishing mortality for the trawl fleet is shown in Figure 11. This is the relationship under the current effort levels being exerted by the longline fleet.

Figure 11 The sustainable yield versus fishing mortality for the trawl fleet under the current effort levels being exerted by the longline fleet.



The results from the age-structured model (that is, the estimate of q) can be used to assess the status of the resource stock over the past decade. The opening stock and closing stock biomass estimates are based on the reported CPUE values multiplied by the catchability coefficient (q); a method suggested by the United Nations (1999) and when combined with reported *catch* data be used to produce a physical flow account (Table 3). Since the management of the stock has been based on a conservative rebuilding strategy we expect the *other changes in volume* to be positive in each year. The *other changes in volume* values are positive for the years over the period 1989 to 1998, but they do vary considerably. The variability can be explained by various factors including (1) measurement errors in catch or effort, (2) environmental conditions impacting on the natural mortality or growth rates and/or (3) weather conditions impacting on CPUE either because the fish behave differently or because the fishing fleets had to modify their tactics.

Overall apart from the low value for the *closing stock* in 1998, the trend in the *opening stock* values shows a slight increase from 1989 to 1998, and this slight increase has resulted in the significant increase (29 per cent) in the *catch* over this time period for the trawl fleet. The initiatives to rebuild the stock are reflected in this increased *catch (trawlers)*. The low value for the *closing stock* in 1998 is based on the reported CPUE values in 1999, a year in which the catch rates were the lowest in 5 years as very strong south-easterlies were thought to have resulted in the hake moving off the bottom. The fleet had to move to less favorable fishing areas (Rob Tilney, pers comm.). Thus *closing stock* value may be under-estimated for 1998 as the fish were not available to the fishery.

Table 3 The physical flow account (all values in '000 tons) for the west coast Cape hake stocks over a ten year period (1989-1998). The catches are the reported landings whereas the opening stock and closing stock biomass estimates are based on the reported CPUE values multiplied by the catchability coefficient (q); a method suggested by the UN (1999). Note that the estimates for the closing stock biomass are based on the reported CPUE for the next year.

Year	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998
Opening stock	338.04	352.34	391.91	390.64	346.98	342.38	312.26	353.62	354.13	415.40
Catch (trawlers)	84.90	78.92	85.52	86.28	98.11	102.77	94.72	91.36	92.33	109.30
Catch (longliners)	0.29	0.39	0.00	0.00	0.00	1.57	0.92	2.40	2.58	0.77
Other changes in volume	98.90	118.11	84.24	42.62	93.51	71.08	135.16	89.47	151.03	15.33
Closing stock	352.34	391.91	390.64	346.98	342.38	312.26	353.62	354.13	415.40	322.21

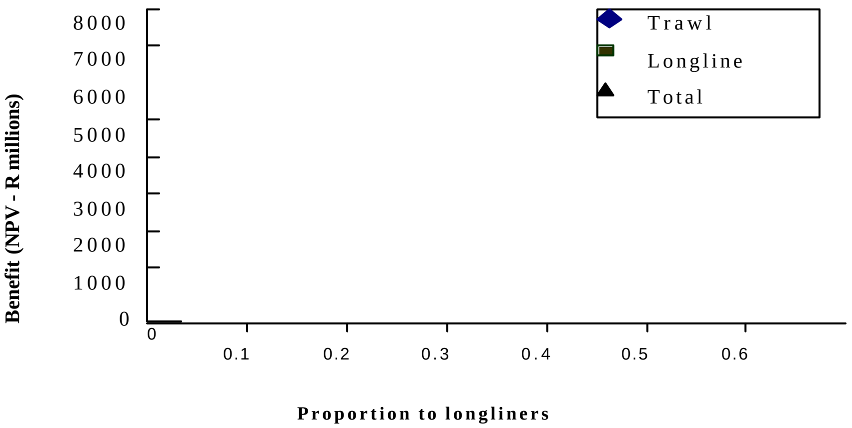
Table 3 also shows the *catch (longliners)* which in comparison to *catch (trawlers)* are much smaller in volume. However the selectivity pattern of longliners is significantly different to those of trawlers and although the values are lower, the impact of longlining is completely different. The value of the biological model used in this analysis is that because it is age-structured it can take explicit account of the differences in selectivity patterns between the gear, something which you can not do in a simple analysis such as that in Table 3. This would provide another possible explanation for the observed variability in the *other changes in volume* values. Although at the current levels of exploitation by longliners the analysis presented in Table 3 does generally suffice in terms of indicating the overall trend in exploitation and stock dynamics.

5.2 Bio-economic simulations of the west coast hake stock

The total benefits under different configurations of trawl and longline effort was computed (see Figure 12). Figure 12 indicates that maximum benefits can be obtained if approximately 15 to 17 per cent of the quota is allocated to longliners. This equates to a TAC for trawl caught hake of about 72 000 tons and a TAC for longline caught hake of about 12 000 tons. It is important to note that the total allowable catch differs according to different configurations of trawl and longline effort as the two sectors have vastly different selectivity functions. An increase in longline effort provides greater benefits, but only under conditions where trawl effort has been reduced (to a TAC of 72 000 tons which is a lower TAC than current catches). The long-term benefits to longliners decrease when high proportions are allocated to this sector (Figure 12) because the cost of effort at high effort levels decreases the profitability of the fleet.

The results from our analysis indicate that the exploitation of the stock could generate a NPV of approximately R7 000 million over the next thirty years if we use cost and price data for the year 2000. Strydom and Nieuwoudt (in press) calculated that an annual rent of R279 million is generated by the South African hake industry (at 1997 lease prices for quota). Thus an annual rent of R184 million would be generated from the west coast (where two thirds of the TAC is harvested). This computes to a NPV of R1 742 million (discounted annual rent estimate multiplied by thirty years), which is less than the R7 000 million estimated in this study. However if we re-do the analysis using price and cost data from 1996 we obtain a NPV of R2 000 million which is close to Strydom and Nieuwoudt's (in press) value. In addition Strydom and Nieuwoudt's (in press) rent estimates are based on the lease price paid to paper quota holders and their values may actually underestimate the potential rent.

Figure 12 The relationship between total benefit (NPV - Rands millions), and benefit to the trawl sector and longline sector and the proportion of the quota allocated to the longline sector. The relationship is based on an increasing cost function relative to fishing effort.



The greatest benefits to the trawl sector can be obtained if there is a reduction in fishing effort (from F=0.3 to F=0.2 year^{-1}) under an assumed cooperative strategy (Figure 13). A difference in profit of R1357 million can be obtained under cooperative strategies versus non-cooperative strategies (for the trawl sector). Thus a cooperative management strategy still remains the best strategy as far as the trawl sector is concerned. The greatest benefits (a difference of R50 million over 30 years) accrues to the longliners if they engage in a non-cooperative strategy and increase F, however these benefits are only achieved if the trawl sector reduces effort (Figure 13). This benefit may be explained as the cost of enforcement the government would have to incur if the policy goal is to maintain longliners at their current effort levels.

Figure 13 Benefits to the trawl sector and longline sector under different scenarios of non-cooperative and cooperative strategies for the West Coast Deep-Sea Hake fishery. The CPUE (t/ std day) after a 30-year period are also shown for each scenario in order to indicate the status of the resource.

		Longliners	
		Non-cooperative	Cooperative
Trawlers	Non cooperative	Trawl = R3599 million **Total = R4340 million** **(CPUE = 1.01)** Longliners = R741 million	Trawl = R3876 million **Total = R4702 million** **(CPUE = 1.31)** Longliners = R825 million
	Cooperative	Trawl = R4967 million **Total = R6340 million** **(CPUE = 3.80)** Longliners = R1372* million	Trawl = R5233 # million **Total = R6555 million** **(CPUE = 4.26)** Longliners = R1322 million

- Greatest benefits to trawl sector if reduce F (from F=0.3 to F=0.2), reduce quota by 10 000tons.
* Greatest benefits to longliners if they increase F, but benefits are only available if rawl sector reduces effort.

The CPUE which is a reflection of stock status shows a slight decline in this scenario

Assumptions
Trawl sector non-cooperative strategy: F= 0.3
Trawl sector cooperativestrategy: F = 0.2
Longline sector non-cooperative strategy: F= 0.8
Longline sector cooperative strategy: F = 0.05

6. DISCUSSION

6.1 Trawling versus longlining

Officially the Department (DEA&T) has attempted to contain the overall longline quota to a small percentage of the overall TAC, the main reasons being resource considerations (sustainability) and information concerns. As the number of participants increase the less chance exists that the information being obtained from the fishery is reliable. The Department is also aware of the market constraints. Marine and Coastal Management (ex-SFRI) have attempted to place more attention on assessing the impact of longlining using age-structured models and establish a more effective monitoring and control system before the overall longline quota is increased further. MCM also plans to continue to collect socio-economic information, thus the overall quota is constrained along the lines of the original experiment. From the analysis, it appears that the Department is aware of the fact that longline effort can only be increased under a strategy where trawl effort is reduced.

The fundamental question is what proportion of the overall hake deep-sea quota for area 1.6 (West Coast) should be allocated to the longliners? The government declared in 1998 that the longline quota would be 4 400 tons. There were 800 applicants for longline permits in 1998 and 1 200 in 1999. At the beginning of 1999 the deep-sea fleet were fishing against 40 per cent of their quotas, and a judicial review was underway in the High Court. Announcements in March 1999 indicated the reduction of the trawl quota would be 20 per cent, from 80 000 tons to 64 000 tons. It was not clear whether the 14 000 tons difference will be trawled or longlined. During May a decision was made to allocate 10000 t from the trawl sector to the Minister which would be given to previously disadvantaged and small and medium-sized enterprises, in most cases longliners.

It appears that the government is hesitant to make decisions that will affect each sector as they are not able to fully compute the economic effects under different configurations of trawl and longline effort. The results of the Longline experiment were based on "what if"- scenarios, that is hypothetical changeovers entirely to longlining assuming the changeover could be completed in 1 year (that is trawling in 1996 to be followed by longlining in 1997), a very unlikely scenario (Anon. 1998). During this period (only 1 year) trawling had profits of R752 million per annum with employment figures of 7795 people whereas it was predicted that longlining would result in profits of R894 million per annum and employ 7 150 people (Anon. 1998). These assessments only provide values for one year and are not based on a dynamic analysis. In this paper the long term benefits are evaluated with a dynamic bio-economic model, which indicate that in the long term the greatest benefits can be obtained with a 15 to 17 per cent of the quota being allocated to longliners. The current allocation to longliners under a conservative management policy is approximately 10 per cent depending on the number of longline permits issued. This current allocation (10 per cent) is close to 15 to 17 per cent allocation considering the uncertainties inherent in any analysis which relies in limited data. The longline sector has only had an impact on the stock over the last 7 years. There is considerable uncertainty as to whether the model parameters can provide good estimates of the effects of the longline sector from the trend in the trawl CPUE data. This weakness in the assessment is due to the sector only becoming significant at a very late stage in the fishery rather than on the techniques used in this assessment. The benefits of a further 5 to 7 per cent increase in the allocation to the longline sector may not justify the risk, as the benefits only reflect a 8 per cent increase in the NPV.

6.2 Non-cooperative versus cooperative management

The central government is responsible for the management of South Africa's shared stocks and makes collective choice rules on behalf of license holders who act in their own interests. The objective of this paper was to include economic factors and consider the effects of the alternative management strategies for two competing sectors (longline versus trawl). Game theoretic modeling was used to evaluate outcomes of assumed non-cooperative versus cooperative management. The results show that the greatest benefits to

the trawl sector occur if they reduce F under a cooperative strategy. An amount of R1 357 million is obtained if the trawl sector follows a cooperative strategy in the future (over the next thirty years) and this strategy is not qualitatively sensitive to the discount rate. However as the discount rate increases the benefits decrease quantitatively. In any event a cooperative management strategy still remains the best strategy as far as the trawl sector is concerned. The extensive government-industry (the trawl sector) commitments to rebuilding has reversed the declining trends in CPUE observed in the 1960s and 1970s, and it is beneficial as far as the trawl sector are concerned for them to engage in cooperative strategies.

The government is redistributing quota to new entrants and previously disadvantaged South Africans, resulting in competition between the established demersal trawl fleet and a new longline sector for access rights. The greatest benefits (R50 million over thirty years) accrues to the longliners if they engage in a non-cooperative strategy and increase F, however these benefits are only achieved if the trawl sector reduces effort (Figure 13). This benefit will be felt as the cost of enforcement the government would have to spend if they wish to maintain longliners at their current effort levels. The current re-structuring and institutional changes are thus impacting on the extensive interaction that existed in the past between the industry and the government. The challenge in the future is for the government to engage in co-management arrangements, which replicate the successful agreements of the past with all the stakeholders; that is, both the established industry and the new participants despite the fact that if new participants are longlining it is beneficial for them to engage in non-cooperative strategies.

7. REFERENCES

Alfsen, K.H. 1996. Macroeconomics and the environment: Norwegian Experience. In: *Macroeconomics and the environment*. Ved. P. Gandhi (Ed.) International Monetary Fund. Pages: 165-186.

Amstrong, C. and O. Flaaten. 1991. The optimal management of a transboundary fish resource: the Arcto-Norwegian cod stock. In: *Essays on the economics of migratory fish stocks*. R. Arnason and T. Bjørndal (Eds.) Springer-Verlag, Berlin, pp 137-150.

Andrew, P.A. 1986. Dynamic catch-effort models for the southern African Hake populations. *Rep. Benguela Ecol. Progm. S. Afr*. 10: 248 pp.

Andrew, P.A. and Butterworth, D.S. 1987. Is $f_{0.1}$ an appropriate harvesting strategy for the Cape hakes? In: The Benguela and Comparable Ecosystems. Payne A.I.L., Gulland J.A., and K.H. Brink (Eds). *S. Afr. J. mar. Sci*. 5: 925-935.

Andrew, P.A., Butterworth, D.S.and Punt, A.E. 1989. Analysis of the Cape hake stock in Division 1.6 using an extension of the Butterworth-Andrew estimation procedure which takes biomass surveys into account. *Colln Scient. Pap. int. Commn SE. Atl. Fish*., 16(1): 15-30.

Anon, 1992. Exploitation if Demersal Resources Using Longlines, Handlines and the Interaction with Otter Trawl Fisheries. Demersal Working Group (DWG), Department of Environmental Affairs, Sea Fisheries Research Institute. Working Document: *WG/02/92/D: H: 8.*

Anon, 1993. Historical overview and scientific perspective of longlining in South Africa prepared by the Sea Fisheries Research Institute for the subcommittee of the SFAC on longlining for hake. Department of Environmental Affairs, Sea Fisheries Research Institute. Working Document: *WG/02/93/D: H: 8.*

Anon, 1995. Report of the Multi-disciplinary task group on the first phase of the longline experiment. Department of Environmental Affairs, Sea Fisheries Research Institute. Working Document: *WG/010/95/D: H: 26.*

Anon, 1998. Final Report. Socioeconomic Investigation of the Hake-directed Longline Experiment. The Multidisciplinary Task Group (MTG), Cape Town, March 1998.

Armstrong, M.A. and Japp, D.W. 1992. Longlining vs Otter trawling in the Hake fishery. Sea Fisheries Research Institute, *WG/01/92/D:H:3, 11pp.*

Badenhorst, A. 1995. Hake-directed Longline Experiment. Demersal Working Group (DWG), Department of Environmental Affairs, Sea Fisheries Research Institute. Working Document: *WG/09/95/D: H: 15.*

Bartelmus, P. 1996. Environmental accounting: a framework for assessment and policy integration. In: *Macroeconomics and the environment*. Ved. P. Gandhi (Ed.) International Monetary Fund. Pages: 107-135.

Beverton, R.J.H. and Holt, S.J. 1957. On the dynamics of exploited fish populations. U.K. *Min. Agric. Fish Invest*. (Ser. 2) 19: 533pp.

Bloem, A.M. and E. Weisman. 1996. National accounts and the environment. In: *Macroeconomics and the environment*. Ved. P. Gandhi (Ed.) International Monetary Fund. Pages: 136-150.

Botha, L. 1973. Migrations and spawning behaviour of the Cape hakes. *S. Afr. Shipp. News Fish. Ind. Rev*. 28(4): 62, 63, 65, 67.

Botha, L. 1980. The biology of the Cape Hakes *Merluccius capensis* Cast and *M. paradoxus* Franca in the Cape of Good Hope area. Ph.D. thesis, University of Stellenbosch: 182pp.

Butterworth, D.S., Punt, A.E. and R.B. Thomson 1992. The relative biological merits of trawl and longline fisheries for hake. Demersal Working Group (DWG), Department of Environmental Affairs, Sea Fisheries Research Institute. Working Document: *WG/01/92/D: H: 25*

Chalmers, D.S. 1976. Weight conversion factors, length/ weight relationships, and annual landings of the South Afircan trawl-caught fish. *Fish. Bull. S. Afr.* 8: 1-4.

Clark, C.W. 1981. Bioeconomics of the ocean. *Bioscience* 31: 231-237.

Clark, C.W. 1990. *Mathematical bioeconomics: the optimal management of renewable resources*. 2nd edition. John Wiley and Sons, Inc.

Clark, C.W. and G.R. Munro. 1982. The economics of fishing and modern capital theory: a simplified approach. In: *Essays in the economics of renewable resources*. L.J. Mirman and D.F. Spulber (Eds.). North-Holland Publishing Company, pp.: 31-54.

Clark, C.W. and G.R. Munro. 1994. Renewable resources as natural capital: the fishery. In: *Investing in natural capital: the ecological economics approach to sustainability*. AnnMari Jannsson (Ed.). Island Press, Washington, D.C. Press.

Clark, C.W., F.H. Clarke, and G.R. Munro. 1979. The optimal exploitation of renewable resource stocks: problems of irreversible investment. *Econometrica*, 47(1): 25-48.

Crawford, R.J.M., Shannon, L.V. and D.E. Pollock. 1987. The Benguela ecosystem 4. The major fish stocks and invertebrate resources. In: *Oceanography and Marine Biology. An Annual Review* 25. Barnes, M. (Ed.). Aberdeen; University Press: 353-505.

Crawford, R.J.M., Shannon, L.V. and D.E. Pollock. 1987. The Benguela ecosystem 4. The major fish stocks and invertebrate resources. In: *Oceanography and Marine Biology. An Annual Review* 25. Barnes, M. (Ed.). Aberdeen; University Press: 353-505.

Crowards, T.M. 1996. Natural resource accounting. *Environmental and Resource Economics* 7(3): 213-241.

Daly, H.E. 1996. *Beyond growth: the economics of sustainable development*. Beacon Press, Boston.

Dasgupta, P. and K-G. Mäler. 1999. Net national product and social well-being. The Beijer Institute Of Ecological Economics - The Royal Swedish Academy of Sciences. Paper No. 125.

Doll, J.P. 1988. Traditional economic models of fishing vessels: a review with discussion. *Mar. Res. Econ*., 5: 99-123.

El Serafy, S. and E. Lutz. 1989. Environmental and natural resource accounting. In: *Environmental management and economic development*. G. Schramm and J.J. Warford (Eds.). A World Bank Publication.

Fowkes, S. and Sowman, M. 1994. Proceeding of the Workshop on Hake Longlining experiment 23 and 24 February 1994. *EEU Report Number* 5/94/116.

Geromont, H., D. Butterworth, D.S., Japp, D. and R. Leslie 1995a. Preliminary Assessment of Longline Experiment West Coast Hake. Demersal Working Group (DWG), Department of Environmental Affairs, Sea Fisheries Research Institute. Working Document: *WG/09/95/D: H: 15*.

Geromont, H., D. Butterworth, D.S., Japp, D. and R. Leslie 1995b. Preliminary Assessment of Longline Experiment South Coast Hake. Demersal Working Group (DWG), Department of Environmental Affairs, Sea Fisheries Research Institute. Working Document: *WG/11/95/D: H: 28*.

Gilbert, A. and W. Hafkamp. 1986. Natural resource accounting in a multi-objective context. *Annals of Regional Science*. 20(3): 10-37.

Hart, P. 1998. Enlarging the shadow of the future: avoiding conflict and conserving fish. In: *Reinventing Fisheries Management*. T.J. Pitcher, P.J.B. Hart and D. Pauly (Eds.). Chapman and Hall, London, pp. 227-238.

Hilborn, R. 1990. Estimating the parameters of full age-structured models from catch and abundance data. *Bull. Int. North Pac. Fish. Comm.*, 50: 207-213.

Hull, B. 1993. Valuing the environment: full cost pricing - an inquiry and a goal. *The Conference Board of Canada*. *Report* 103-93.

Hutton, T. 1992. The status and productivity of the Cape hake stock off the west coast of South Africa based on an age-structured production model with different stock-recruitment and fishing selectivity-at-age relationships. Unpublished Masters Dissertation, Zoology Department**,** University of Cape Town, South Africa.

Japp, D.W. 1993. Longlining in South Africa. In: *Fish, Fishers and Fisheries*. Proceedings of the Second South African Marine Linefish Symposium, Durban, 23-24 October, 1992. Beckley, L.E. and R.P. van der Elst (eds). Oceanographic Research Institute, Marine Parade, Durban, South Africa. Pages: 134-159.

Japp, D.W. 1995a. Report submitted to the Longline Management committee on the hake directed longline pilot study conducted from 23 May 1994 to 31 May 1995. Department of Environmental Affairs, Sea Fisheries Research Institute, Cape Town. Working Document: *WG/09/95/D: H: 16*.

Japp, D.W. 1995b. Strategy to test the feasibility of hake-directed longlining in South Africa (Phase 2 – *Experimental Fishery*). Demersal Working Group (DWG), Department of Environmental Affairs, Sea Fisheries Research Institute. Working Document: *WG/11/95/D: H: 29*.

Japp, D.W. 1995c. Summary of the Hake Fishery in 1993. Demersal Working Group (DWG), Department of Environmental Affairs, Sea Fisheries Research Institute. Working Document: *WG/05/94/D: H: 7*.

Japp, D.W. 1995d. Summary of the Hake Fishery in 1994. Demersal Working Group (DWG), Department of Environmental Affairs, Sea Fisheries Research Institute. Working Document: *WG/05/95/D: H: 8b*.

Japp, D.W. 1995e. Historical overview of longlining in South Africa. Demersal Working Group (DWG), Department of Environmental Affairs, Sea Fisheries Research Institute. Working Document: *WG/DEM/93/02/H: 8*.

Japp, D.W. 1996. Summary of the Hake fishery in 1995. SFRI Working document *WG/05/64/D:H: 7*

Jones, B.W. and Van Eck, T.H. 1967. The Cape Hake: its biology and the fishery. *S. Afr. Shipp. News Fish. Ind. Rev.*, 22(11): 90-97.

Kaitala, V. and G. Munro. 1993. The economic management of high seas fishery resources: some game theoretic aspects. Department of Economics, University of British Columbia, Vancouver, B.C. Canada. Discussion Paper No.: 93-41.

Kreps, D.M. 1990. *Game Theory and Economic Modelling*. Claredon Press. Oxford.

Lai, A. 1997. Natural Resource Accounting for Thailand's forests: a theoretical framework. International and Development Studies Working Paper. Queen's University, John Deutsch Institute for the Study of Economic Policy.

Lange, G-M. 1998. An approach to sustainable water management in Southern Africa using natural resource accounts: the Experience of Namibia. *Ecological Economics* 26(3): 299-311.

Leefers, L.A. and G.B. Castillo. 1998. Bridging the gap between economics and ecology. *Conservation Ecology* (online) 2(2):19.

Leslie, R.W. 1998. Final data document for west coast hake assessments. Sea Fisheries Research Institute. Working Group Document *WG/03/98/D:H:12*

Lewis, T.R. and J. Cowens, 1982. The Great Fish War: a cooperative solution. University of British Columbia, Department of Economics. *Programme in Natural Resources Economics*. *Resources Paper No*. 84.

Moffat, I. 1996. *Sustainable development: principles, analysis and policies*. The Parthenon Publishing Group, London.

Munro, G.R. 1979. The optimal management of transboundary renewable resources. *Can. J. Econ*., 12(8): 355-376.

Munro, G.R. 1981. The economics of fishing: an introduction. In: *Economics and Resources Policy*. J. A. Butlin (Ed.). Longman, London, pp.: 129-140.

Munro, G.R. 1987. The management of shared fishery resources under extended jurisdiction. *Mar. Res. Econ*., 3(4): 271-296.

Munro, G.R. 1990. The optimal management of transboundary fisheries: game theoretic considerations. *Natural Resource Modeling* 4(4): 403-426.

Munro, G.R. 1992. Mathematical bio-economics and the evolution of modern fisheries economics. *Bulletin of Mathematical Biology* 54(2/3): 163-184.

Munro, G.R. 1994. Coastal states and distant water fleets under extended jurisdiction: the search for optimal incentive schemes. In: *Advances in Dynamic Games and Applications*. T. Basar and A. Haurie (Eds.). Birkhauser, Boston, pp.: 301-317.

Munro, G.R. 1996. Approaches to the economics of the management of High Seas fishery resources. In: *Fisheries and Uncertainty: A precautionary approach to resource management*. D.V. Gordon and G.R. Munro (Eds.). University of Calgary Press, pp. 161-180.

Munro, G.R. 1998. The economics of overcapitalization and fishery resource management: a review. Discussion Paper No.: 98-21. Department of Economics, University of British Columbia, Vancouver, Canada.

Munro, G.R. and A.T. Scott. 1985. The economics of fisheries management. In: *Handbook of Natural Resource and Energy Economics, Vol 2*. A.V. Kneese and J.L. Sweeney (eds). Elsevier Publishers, B.V, pp.: 623-676.

Nash, J.F. 1951. Non-cooperative games. *The Annuals of Mathematics*, 54(2): 286-295.

Nordhaus, W.D. and E.C. Kokkelenberg (Eds.). 1999. Nature's numbers: Expanding the national economic accounts to include the environment. Panel on Integrated Environmental and Economic Accounting. National Academy Press, Washington, D.C. pp. 250.

OECD. 1997. Towards Sustainable Fisheries. Economic Aspects of the Management of Living Marine Resources. Organisation For Economic Co-operation and Development. OECD Publications, Paris, France. 268pp.

Osborne, M.J. and A. Ruberstein. 1994. *A Course in Game Theory*. The MIT Press. Cambridge, Massachusetts.

Ostrom, E., Gardner, R. and J. Walker 1997. *Rules, Games, and Common-Pool Resources*. The University of Michigan Press, Ann Arbor.

Payne, A.I.L. 1989. Cape Hakes. In: *Oceans of Life off Southern Africa*. Vlaeberg, Cape Town. pages 136-147, Payne, A.I.L. and R.J.M. Crawford (Eds).

Payne, A.I.L. and A.E. Punt. 1992. Biology and fisheries of South African Cape hakes (*M. capensis* and *M. paradoxus*). Pages 15-47, In: *Hake: Biology, fisheries, and markets*. Alheit, J. and T.J Pitcher (Eds).

Payne, A.I.L. Rose, B. and Leslie, R.W. 1987. Feeding of hake and a first attempt at determining their role trophic role in the South African west coast marine environment. In: *The Benguela and Comparable Ecosystems*. Payne, A.I.L., Gulland, J.A. and K.H. Brink (Eds). *S. Afr. J. mar. Sci*. 5: 471-501.

Payne, A.I.L., Badenhorst, A., Augustyn, C.J. and Leslie, R.W. 1989. Biomass indices for Cape hake and other demersal fish species in South African waters in 1988 and earlier. *Colln Scient. Pap. int. Commn SE. Atl. Fish*., 16(2): 25-62.

Prudham, W.S. and S. Lonergan. 1993. Natural resource accounting (I): A review of existing frameworks. *Canadian Journal of Regional Science* 16(3): 363-386.

Punt, A.E. 1988. Model Selection for the Dynamics of South African Hake Resources. M.Sc. Thesis. University of Cape Town, South Africa. *Rep. Benguela Ecol. Progm. S.Afr*. 15:[vii] + 395 pp.

Punt, A.E. 1990. Is B1 = K an appropriate assumption when applying an observation error production model estimator to catch-effort data. *S. Afr. J. mar. Sci*. 9: 249-259.

Punt, A.E. 1991. Management procedure for Cape Hake and Baleen Whale resources. Ph.D.. Thesis. University of Cape Town, South Africa. *Rep. Benguela Ecol. Progm. S.Afr.* 23:[viii] + 689 pp.

Punt, A.E. 1992. Selecting management methodologies for marine resources, with an illustration for southern African hake. In: Benguela Trophic-Functioning. Payne, A.I.L., Brink, K.H. Mann, K.H., and R. Hilborn (Eds). *S. Afr. J. mar. Sci*., 12: 943-958.

Punt, A.E. 1993. Assessments of the stocks of Cape hake (*Merluccius spp*.) off South Africa. *S. Afr. J. mar Sci.* 13

Punt, A.E. and Leslie, R.W. 1991. Estimates of some biological parameters for the Cape hakes off the South African west coast. *S. Afri. J. mar. Sci*., 10: 271-284.

Rasmusen, E. 1995. *Games and Information: An Introduction to Game Theory*. Blackwell, Cambridge, MA.

Repetto, R., Magrath, W., Wells, M., Beer, C. and F. Rossini. 1989. Wasting assets: natural resources in the national income accounts. World Resources Institute. 68pp.

RAU, 2000. Rights Allocation Unit. Draft discussion document for the fisheries management plan to improve the process of allocating fishing rights. August, 2000. (Version 6.1), 48p.

Roux, ER. 1949. Migrations of the Cape hake or stockfish (*Merluccius capensis* Cast) on the west coast of South Africa. *Trans. R. Soc. S. Afri.* 32(2): 217-231.

Saville, A.D. 1997. A Computable Dynamic Bioeconomic model of the Optimal Utilisation and Management of South Africa's Renewable Marine Resources: a case Study of the Hake Fishery. Unpublished thesis, Doctor of Philosophy in the Department of Economics, University of Natal, Durban (December 1997).

SFRI 1993. *South African Commercial Fisheries Review* 1991, No. 1. Chief Directorate Sea Fisheries (Cape Town), Department of Environmental Affairs, Republic of South Africa. 41pp.

Stander, G. 1995. Aspects of the development and the regulation of South Africa fisheries. In: *Review of International Experiences in Access Rights and their implications for Fisheries Management in South Africa*. Access Rights and Resource Implications Task Group (ARRITG), pp. 51-72. Sea Fisheries Research Institute. Cape Town, South Africa.

Strydom, M.B. and W.L. Nieuwoudt (in press). Restructuring the management of the South African hake fishery: analysis of industry attitudes. *S. Afr. J. mar. Sci.* 22

Stuttaford, M. (Ed.) 1993. *South African Fishing Industry Handbook and Buyer's Guide*. Marine Info. Services (Pty) Ltd.

Stuttaford, M. (Ed.) 1996. *South African Fishing Industry Handbook: South Africa, Namibia and Moçambique*. 24th Edition. Marine Information cc, Stellenbosch, South Africa.

Sumaila, U.S. 1995. Irreversible capital investment in a two-stage bi-matrix fishery game model. *Mar. Res. Econ*., 10: 263-283.

Sumaila, U.S. 1997. Cooperative and non-cooperative exploitation of Arcto-Norwegian Cod Stock. *Environmental and Resource Economics* 10: 147-165.

Sumaila, U.S. 1999. A review of game-theoretic models of fishing. *Marine Policy* 23(1): 1-10.

United Nations, 1993. Integrated environmental and economic accounting. Studies in methods, Handbook of national accounting, Series F, No. 61. United Nations, New York, pp. 182.

United Nations, 1999. Integrated environmental and economic accounting. An operational manual, Series F, No. 78. United Nations, New York, pp. 239.

Van Eck, T.H. 1969. The South African hake *'Merluccius capensis'* or *'Merluccius paradoxus'*. *S. Afr. Shipp. News Fishg Ind. Rev.* 24(5): 95-97.

von Neumann, J. and O. Morgenstern. 1944. *Theory of Games and Economic Behavior.* Princeton Univerity Press. Princeton.

Weintraub, E.R. (Ed.). 1992. *Toward a History of Game Theory*. Duke University Press. Durham and London.

Yeto, S.C., Garcia, R.G. and G.R. Bravo. 1997. Potential gains from co-operation for vessels and countries. *Marine Resource Economics* 12: 145-158.